Biodiversity conservation and pest control in agricultural landscapes: Multigraph analysis to meet multiple ecological objectives in a biological corridor in Costa Rica

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Introduction

• One of the greatest threats to biodiversity worldwide is the loss and fragmentation of habitat due to human activities such as agriculture and forestry[1].

• In tropical regions, home to the vast majority of the world's species, the balancing of conservation with human activities is of tremendous importance[2].

• Recognizing that 'protecting' large swaths of tropical forest from human use (i.e., 'land sparing') is often not a tenable conservation strategy, improving the quality of the agricultural landscape (e.g., by maintaining remnant forest patches) to simultaneously sustain livelihoods and protect biodiversity is a promising approach[2,3].

• High quality agricultural landscapes can mitigate the effects of fragmentation on biodiversity by increasing connectivity between habitat patches, thus buffering metapopulations from regional extinction[3].

• While maintaining and improving landscape connectivity is important for biodiversity, in agricultural landscapes landowners may be interested in reducing connectivity and habitat quality for invasive pest species.

Approach

• Landscape graphs (Figs. 1 & 2) are a promising, and mathematically tractable, approach to modeling landscape connectivity.

• Landscape graphs describe pairwise relationships between landscape features based upon biologically meaningful designations of patch connectivity.

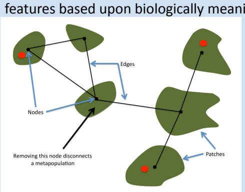

Figure 1. *A simple landscape graph composed of habitat patches, depicted as nodes, connected by edges. Local populations occupying patches are indicated by the red markers.*

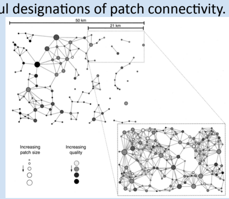

Figure 2. *Nested landscape graphs illustrating scalability based upon dispersal distance and patch size (from Minor and Urban 2007)[4].*

• Advantages of a landscape graph approach include:
  (i) the ability to measure connectivity properties at both the scale of the patch and the network (e.g., network topology) (Figs. 3 & 4)
  (ii) the ability to model connectivity when limited biological data is available
  (iii) improving stakeholders' ability to manage landscapes by identifying 'keystone' patches that confer high levels of connectivity, and
  (iv) providing a framework for unifying metapopulation ecology and landscape ecology in spatially realistic landscapes.

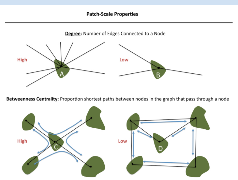

Figure 3. *Properties of nodes in a landscape graph. The number of edges a node contains is the 'degree'. Patch 'A' has a greater degree than patch 'B'. Because the shortest distance between most patches must traverse patch 'C', it has a greater betweenness centrality than patch 'D'.*

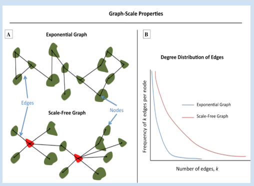

Figure 4. *Properties of the topology of landscape graphs. (A) Graphs with differing typology. Exponential graphs contain a high proportion of patches with a minimal number of edges. Scale-free graphs follow a power law degree distribution, where a few patches are highly connected to others (identified in red). (B) The degree distribution of each graph type.*

Study Area

• The Volcánica Central–Talamanca Biological Corridor (VCTBC) was designated by the Costa Rican government as part of the Mesoamerican Biological Corridor with the purpose of (i) providing biological connectivity between the Volcánica Central Range and La Amistad Biosphere, and (ii) improving environmental quality and the quality of life for the corridor inhabitants.

• The VCBTC is among the three most important coffee-producing regions in Costa Rica.

• Recently, an invasive beetle, the coffee berry borer (CBB, *Hypothenemus hampeii)*, was accidentally introduced into the VCTBC, reducing revenues for landowners.

• Research on the CBB within the VCTBC indicates that CBB abundance is determined in part by landscape factors.

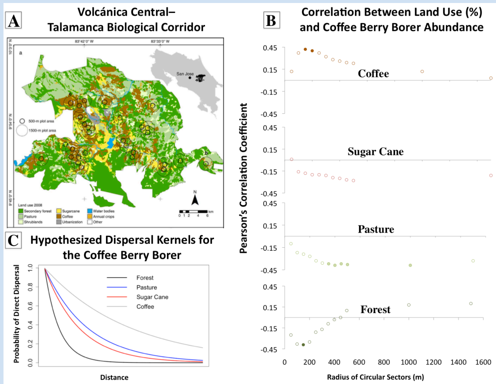

Figure 5. *(A) Landscape description with 500 m and 1500 m circular sectors centered on 29 sample plots (from Avelino et al.)[5]. Percent land-use/land-cover (LU/LC) was determined at spatial scales between 50 m and 1500 m. (B) Correlation between the percent of land use at each spatial scale and maximum coffee berry borer abundance. Filled circles indicate statistical significance (P < 0.05). (C) Hypothesized dispersal kernels between coffee patches for the Coffee Berry Borer according to different LU/LC matrix types.*

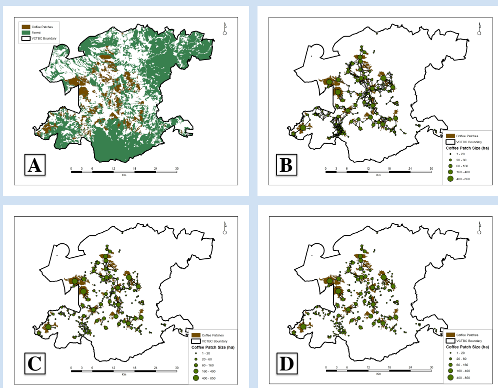

Figure 6. *(A) Distribution of coffee and forest patches within the VCBTC. Initial landscape graphs for coffee patches at 1 km (B), 500 km (C), and 250 km (D) Euclidean distance thresholds for patch connectivity.*

• Initial landscape graphs for coffee patches have been constructed based upon Euclidean distances between patches (Fig. 6). Note the prevalence of forest patches amongst coffee patches. The percentage of forest at intermediate spatial scales was most negatively correlated with CBB abundance compared with other LU/LC types.

Discussion and Future Directions

• Empirical dispersal kernels are being developed for the CBB dispersing from coffee patches into each of the other four LU/LC types. Results of this analysis could help inform future diffusion-based landscape graph modeling efforts for the CBB.

• The partitioning of variance in CBB abundance explained by local and landscape factors is currently being conducted. Results of the local vs. landscape analysis will help inform future control efforts.

• If forest remnants are barriers to the dispersal of CBB, then a landscape graph approach could help identify forest patches that decrease connectivity for the CBB by diminishing the contribution to population persistence:
  (i) at the patch-scale (e.g. reducing the degree or betweenness centrality of a coffee patch)
  (ii) at the landscape graph-scale (e.g., altering the topology of the graph)

• Node removal simulations could help identify patches of importance for increasing connectivity for forest-dependent species, and decreasing connectivity for the CBB.

Challenges

• Landscape connectivity is species specific, as organisms have different dispersal distances and mechanisms, and may experience the matrix as hostile, non hostile, or at some intermediate level.

• It's not always clear what constitutes a patch (e.g., a habitat generalist vs. host-specific organism)

• More empirical evidence is needed to determine if landscape graphs are reasonable approximations of actual connectivity as opposed to simply potential connectivity.

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